Self-Protection, Psychological Externalities and the Social Dynamics of Fear

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Summary

We examine the social dynamics of crime by means of evolutionary game theory, and we model the choice of boundedly rational potential victims to privately self-protect against prospective offenders. Negative externalities from self-protection, as the socially transmitted fear of victimization, can influence the strategic choices of victims even with constant or declining crime rates, and this circumstance may lead to Pareto inefficient equilibria with excessive expenses for private protection. Providing higher levels of public security (or of appropriate social care) financed through discriminatory taxation of private defensive behaviors, can prevent crime and reduce superfluous self-protection, thus driving the social dynamics toward a more efficient equilibrium. Public policy can therefore be effective in implementing the social optimum. This paper extends previous work by Cressman et al. (1998) by increasing the range of possible dynamics and the scope for public intervention. Consequently, in our model, public policy can deter crime and improve the welfare of victims by addressing the intangible aspects of crime, that is, the social dynamics of fear.

Keywords: Self-protection; Fear of Crime; Public security; Psychological externality; Replicator dynamics.

JEL Codes: C73, H23, K49

Self-Protection, Psychological Externalities and the Social Dynamics of Fear

"Managing fear is as important as managing the crime itself"

Sheldon F. Greenberg, former police officer;

cited in Hermann (2009)

1 Introduction

The issue of protection against crime has received in the last decades substantial attention in different disciplinary fields, such as the economics, the sociology and the social psychology of crime and prevention. More recently, a debate has emerged on whether these disciplines should converge (Braithwaite, 2000). The debate has been stimulated by the contemporary transition to a 'risk society' (Beck, 1992), by the expansion of private security (Loader, 1991), and by changes in public policing (Jones and Newburn, 2002). As society becomes increasingly complex, the analysis of crime-related issues should transcend the traditional fields of research (like criminology, economics of crime, and so forth) and become something of general importance to the social sciences, with a new common paradigm. Still, such an interdisciplinary framework seems to lack in the literature. We start to fill this gap by merging into a dynamic framework some general insights from the literature on the economics and fear of crime. We mean this contribution as a preliminary exploration of the issue, which we hope will lead to further investigation in more complex analytical settings.

We propose a simple model that describes the strategic interaction between prospective offenders and potential victims, by means of evolutionary game theory (Weibull, 1995). We also consider the provision of public security, and find the conditions under which public intervention improves welfare. We take as a reference the model by Cressman et al. (1998) and, innovatively, we consider the strategic interaction between potential victims as well as between victims and prospective offenders. Victims can choose to privately self-protect against crime, but this choice inflicts a negative externality on other individuals. This externality can have both a material and psychological component. An example can better explain the difference between the two kinds. If, for fear of robbers, most neighbors avoid walking the streets at night (the self-protective behavior), the lonely ones who do so will be victimized more often (the material externality) because they are less protected by the absence of people around. Additionally, the lonely less protected neighbors will suffer an emotional distress related to the higher fear of victimization (the psychological externality). The presence of psychological externalities represents the main novelty of our paper, and permits to consider in an economic framework the social dynamics of fear of crime.

The exposition is organized as follows. In Section 2, we provide an interdisciplinary review of the relevant literature. In Section 3, we define the model. In Section 4, we present the basic mathematical results. In Section 5, we comment the possible dynamics and we point out the role of psychological externalities. In Section 6, we conduct a policy analysis and study the effects of public security on welfare. In Section 7, we provide the conclusions and implications of the research.

2 Analysis of Literature

The classic economic literature suggests a pretty intuitive concept. When potential victims are rational decision makers, there is typically a potential trade-off between public and private policing, and the most likely outcome is a mix between the two, where the actual weights depend on the productivity and effectiveness of public policing, and, somewhat more subtly, on the risk aversion of potential victims. It is then possible that, in certain circumstances, an increase in public security may ‘crowd out’ private self-protection, as described in the theoretical model by Cressman et al. (1998). This view comes from the foundational study by Becker (1968) and the early contributions by Bartel (1975) and Clotfelter (1977), who find that firms tend to consider public and private policing as substitutes.

A common finding in the economics of crime is that self-protection can cause a *material* externality, because it creates an incentive for offenders to attack the less protected targets (Heal and Kunreuther, 1997). This result originates from the study of the strategic interdependence between offenders and potential victims. Van Dijk (1994) proposes a game-theoretic model in which rational victims and offenders adjust strategically against each other the levels of self-protection and criminal activity. Zhuang and Bier (2007) propose a game in which the attacker has to optimize over a continuous self-defensive effort of the victim, and obtain complex dynamics, including the escalation or setback of the conflict. Bier et al. (2007) invert the problem: the defender has to optimize the protection of multiple targets, among which the attacker has to choose, so that devoting more resources to protect a specific target makes the others more vulnerable. Muermann and Kunreuther (2008) study the optimal self-protection strategies of insured players with positive externalities and suggest that, with appropriate public policies, risk averse players can invest more in self-protection unless the probability of a loss is large enough, as originally found out by Ehrlich and Becker (1972).

The *material* externalities associated with private self-protection have been widely studied by economic and game-theoretical literature, which tends to disregard the psychological aspects of this behavior. The *psychological* externalities have been mostly discussed (and empirically tested) by the socio-psychological literature on fear of crime. This field has reached important but inherently ambiguous research findings, because of the elusive and multidimensional nature of fear. We review what is relevant for the main assumption of this paper, namely, the emotional distress that individuals who self-protect cause to their neighbors.

The existence of a psychological externality from self-protection is rooted in three lines of research: the perceived risk of victimization, the loss of adaptation to crime, and the marketization of security as a positional good. Such variety of explanations reflects the multidimensionality of the issue. Gabriel and Greve (2003), for example, argue that fear of crime has three dimensions: affective (being afraid of the possible offence), cognitive (reasoning about the likelihood of the possible offence), and motivational (conditioning one's own behavior on the possibility of the offence). The study of self-protective choices and their mutual interdependencies should therefore consider all these three aspects.

The perceived risk of victimization has proven to be an important explanatory variable of the fear of crime in the empirical studies by Warr and Stafford (1983), Heath et al. (2001), and Reid and Konrad (2004). Perceived victimization is often considered the cognitive mechanism that informs the fear response to crime (Hale, 1996; Farrall et al. 2007; Chadee, 2013). This theory is coherent with evidence on persistently high levels of fear after a decrease in crime, reported by Lewis and Maxfield (1980), Heath et al. (2001), and Hermann (2009). Similarly, in an empirical study by Roundtree and Land (1996), neighborhoods with high integration reported high levels of safety, but also displayed a high level of fear. Building on this line of literature, the following observation is straightforward. By self-protecting, an individual creates an incentive for the criminal to victimize a less protected neighbor (the material externality), who therefore will perceive a higher risk of victimization and a higher fear of crime (the psychological externality). This conclusion is supported by further empirical research. Jackson (2008) finds that perceived vulnerability mostly affects the worry about crime through judgments of absolute and *relative* risk, where the latter was assessed at neighborhood level by respondents in a questionnaire study.

Covington and Taylor (1991) find that fear is strongly influenced by within-neighborhood factors. Cook (1977) points out that self-protective behaviors can improve rather than reduce crime opportunities, thus generating both material and psychological externalities. For example, thieves may gain from people who avoid walking the streets at night, because their precautionary behavior makes the others who still walk more vulnerable to crime.

The second line of research on the psychological externality of self-protection, is the loss of adaptation to crime. If individuals were previously adapted to local crime rate, and if they take steps to cope with the risk of victimization, such precautionary behavior can increase their fear or worry about crime because it reminds them the risks and the potential costs of being a victim. This theory has been suggested by Taylor and Shumaker (1990), who rely on previous empirical results by Rosenbaum (1988) and Liska et al. (1988). A fortiori, individuals previously adapted to local crime rate, can increase their fear or worry about crime also when observing the precautionary behavior of their neighbors, which therefore generates a psychological externality. This hypothesis is supported by various studies. In an empirical analysis, Norris and Johnson (1988) find that self-protective measures (such as locking doors and windows, leaving lights on, and so forth) have little impact on victimization rate and on the control of fear. Kidder and Cohn (1979) suggest that such self-protective measures can also generate fear. Norton and Courlander (1982), and Silverman and Della-Giustina (2001) argue that also public security policies may actually feed fear, rather than curbing it.

The third and last line of research, related to the psychological externality in our model, is the marketization of security as a positional good. Such theory relies on the analyses by Loader (1999) and Newburn (2001), who argue that the increase in demand for private policing may signal the advent of a post-modern consumer culture leading to the commodification of security. This phenomenon has been accompanied and somewhat favored by parallel changes in public policing and crime control (Jones and Newburn, 2002; Zedner, 2006). The emergence of psychological externalities from self-protection can be then explained as follows. If individuals care about their *relative* safety (in addition to their absolute safety) the less-protected individuals may emotionally suffer from falling behind their neighbors in the social competition for being more secure. This effect is known as “keeping up with the Joneses” and is widely recognized by economists as an important determinant of well-being (see, among others, Frey and Stutzer, 2002; Luttmer, 2005).

3 The model

We propose an evolutionary game between potential victims and potential offenders. An example can help to understand the logic behind the model. If most neighbors avoid walking the streets at night (the self-protective behavior) to avoid robbers, the lonely ones who do so will be victimized more often (the material externality) and will also suffer a higher fear of crime (the psychological externality). The game might be considered a stylized representation of this example, but it can also represent various other types of crime and self-protective behaviors.

The game works as follows. At each moment in (continuous) time, there is a large number of random encounters among members of the two populations of potential victims and potential offenders. In each encounter, two potential victims *N1* and *N2* (‘the neighbors’) are randomly matched with a prospective offender *CR*, and they all play a one-shot game. Each neighbor can choose between two strategies: to privately self-protect against victimization or not to do so (strategies *P* or *NP*, respectively), and such decision is observable by other players. The prospective offender can choose between two strategies: to assault one neighbor (strategy *A*) or not to assault anybody (strategy *NA*). The offender who plays strategy *A* will assault a randomly-picked neighbor if the two neighbors choose the same strategy (and have therefore the same level of protection), otherwise the offender will assault the neighbor who does not self-protect. Players choose the strategy simultaneously, without knowing ex ante the other players' choices.

The payoffs of the neighbors are symmetric, and are represented in the following matrix (which, for simplicity, is referred to the neighbor *N1*):

$$\begin{array}{ccccc} & A, P_{N2} & A, NP_{N2} & NA, P_{N2} & NA, NP_{N2} \\ P_{N1} & -\alpha - \frac{1}{2}\beta_1 - \gamma_1 & -\alpha & -\alpha - \gamma_1 & -\alpha \\ NP_{N1} & -\beta_2 - \gamma_2 & -\frac{1}{2}\beta_2 & -\gamma_2 & 0 \end{array} \quad (1)$$

The payoff matrix above has the following notation. The parameter $\alpha > 0$ represents the cost of the private self-protective strategy *P*. The parameters β_1 and β_2 represent the damage incurred by the victim of criminal assault who adopted, respectively, the strategies *P* and *NP*. We assume that victims who privately self-protect have a lower damage if assaulted, that is $0 \le \beta_1 < \beta_2$. Note that, if $\beta_1 > 0$, then strategy *P* does not provide full protection to the victim (whereas it provides full protection if $\beta_1 = 0$). The parameters γ_1 and γ_2 represent the emotional distress suffered by an individual when her neighbor privately self-protects. This negative externality is γ_1 when also the distressed individual privately self-protects, and it is γ_2 otherwise. We assume $0 \le \gamma_1 < \gamma_2$, that is, the distress is lower when both neighbors privately self-protect.

In the payoff matrix (1), we have assumed that the two neighbors equally share the risk of being assaulted if they choose the same strategy. Indeed, the expected damage for criminal assault is $\beta_1/2$ if both neighbors self-protect, and $\beta_2/2$ if none of them self-protects. Conversely, if their choices diverge, the one who self-protects will not be victimized while the other less protected neighbor will surely be the victim should the prospective offender decide to assault.

The meaning of parameters γ_1 and γ_2 comes from the literature on fear of crime. For example, individuals previously adapted to local crime rate, can increase their fear or worry about crime when observing the precautionary behavior of their neighbors, which reminds them the risks and the potential costs of being a victim.[1] This hypothesis is coherent with the theory by Taylor and Shumaker (1990) and with relevant empirical research (see also Section 2). The assumption $\gamma_1 < \gamma_2$ relies on the perception, by the less-protected neighbor, of a higher risk of victimization (which can generate fear, see Heath et al., 2001) and of a lower social position (which can generate unhappiness, see Frey and Stutzer, 2002). The empirical and theoretical literature that supports our assumption is reviewed in Section 2.

The payoffs for the prospective offender of assaulting (strategy *A*) and not assaulting (strategy *NA*) are:

$$\begin{array}{ccccc} & P_{N1}, P_{N2} & P_{N1}, NP_{N2} & NP_{N1}, P_{N2} & NP_{N1}, NP_{N2} \\ A & a & b & b & c \\ NA & d & d & d & d \end{array} \qquad (2)$$

We postulate that $c \geq b > a$, while we do not make any assumption on *d*. The meaning of these conditions is straightforward. The best possible situation for the offender is when none of the two potential victims self-protects, whereas the worst possible situation is when both potential victims self-protect. The parameter *d* represents the payoff for the prospective offender of not assaulting anyone, and its value can vary depending on the availability of alternative sources of income (either legal or not).

We denote by $x(t)$ the share of potential victims who choose to privately self-protect (strategy *P*) and by $y(t)$ the share of prospective offenders who choose to assault (strategy *A*), within their respective total populations.[2] From the payoff matrix (1), the expected payoffs of potential victims from playing strategies *P* and *NP* are given respectively by:

$$\Pi^{P} = -\left(\alpha + \frac{1}{2}\beta_1 + \gamma_1\right)xy - \alpha(1-x)y - (\alpha+\gamma_1)x(1-y) - \alpha(1-x)(1-y) \tag{3}$$

$$\Pi^{NP} = -(\beta_2 + \gamma_2)xy - \frac{1}{2}\beta_2(1-x)y - \gamma_2 x(1-y) \tag{4}$$

The payoff differential of self-protecting (strategy *P*) with respect to its alternative strategy *NP* is:

$$\Pi^{P} - \Pi^{NP} = \frac{\beta_2 - \beta_1}{2}xy + (\gamma_2 - \gamma_1)x + \frac{\beta_2}{2}y - \alpha$$

From the payoff matrix (2), the expected payoffs of prospective offenders from playing strategies *A* and *NA* are given respectively by:

$$\Pi^{A} = ax^2 + bx(1-x) + b(1-x)x + c(1-x)^2$$

$$\Pi^{NA} = d$$

The payoff differential of assaulting (strategy *A*) with respect to its alternative strategy *NA* is:

$$\Pi^{A} - \Pi^{NA} = (a + c - 2b)x^2 - 2(c-b)x + c - d$$

We describe via the standard replicator dynamics the time evolutions of the share *x* of potential victims playing strategy *P* and of the share *y* of prospective offenders playing strategy *A*, in their respective total populations. Accordingly, the growth in the share of population adopting a certain strategy is proportional to the difference between the expected payoff of that strategy and the expected payoff of its alternative. The system dynamics are given by:

$$\begin{cases} \dot{x} = x(1-x)\left(\Pi^{P} - \Pi^{NP}\right) \\ \dot{y} = y(1-y)\left(\Pi^{A} - \Pi^{NA}\right), \end{cases} \tag{5}$$

where $\dot{x}$ and $\dot{y}$ represent the time derivatives of the shares *x* and *y*, respectively. The replicator dynamics is a learning-by-imitation model widely used in economics (see Hofbauer and

Sigmund, 1988; Björnerstedt and Weibull, 1995; Sacco, 1995; Weibull, 1997; Schlag, 1998; Antoci and Sacco, 1995, 2002). It postulates that players are boundedly rational, they learn from each other and they tend to adopt the strategy that performs better than the other. Then, relatively successful behaviors will be replicated, while unsuccessful behaviors will be gradually abandoned. Our model combines such process of cultural selection with innovative features like the interplay between material and psychological consequences of criminal and self-protective behaviors, and the strategic interaction between potential victims as well as between victims and prospective offenders.

4 Basic mathematical results

4.1 Equilibrium points

The dynamical system (5) is defined in the unit square $Q = \{(x, y) \in [0,1]^2\}$. We denote: by $Q_{x=0}$ the side of the square Q where $x = 0$; by $Q_{x=1}$ the side where $x = 1$; by $Q_{y=0}$ the side where $y = 0$; and by $Q_{y=1}$ the side where $y = 1$.

All sides of the square are invariant, meaning that an initial situation (x, y) that lies on one side can only evolve along that side. This property depends on the learning-by-imitation nature of the replicator dynamics. We recall that x represents the share of potential victims who privately self-protect, while y the share of prospective offenders who assault, within their populations. If the state (x, y) initially lies on one side of the square, every individual in one population plays the same strategy, no alternative is observable and therefore such population cannot learn how to change. For the same reason, the states $\{(x, y) = (0,0),(0,1),(1,0),(1,1)\}$ at the vertices of the square are always equilibrium points of the dynamical system (5). In such states, each population of potential victims and prospective offenders plays only one strategy. In $(x, y) = (0,0)$, nobody privately self-protects nor assaults: We call this scenario “Peace”. In $(x, y) = (1,1)$, everybody privately self-protects or assaults: We call this scenario “All-Round Fight”. In $(x, y) = (0,1)$, no potential victim privately self-protects and every prospective offender assaults: We call this scenario “Surrender”. In $(x, y) = (1,0)$, every potential victim privately self-protects and no prospective offender assaults: We call this scenario “Deterrence”.

In addition to the four vertices of the square (each representing a conflict scenario) there can be other three equilibrium points. The equilibrium point F_1 corresponds to the intersection, when existing, between the interior of the side $Q_{y=0}$ and the curve defined by $\Pi^P - \Pi^{NP} = 0$. The equilibrium point F_2 corresponds to the intersection, when existing, between the interior of the side $Q_{y=1}$ and the curve defined by $\Pi^P - \Pi^{NP} = 0$. The equilibrium point F corresponds to the intersection, when existing, in the interior of the square Q between the curves $\Pi^P - \Pi^{NP} = 0$ and $\Pi^A - \Pi^{NA} = 0$. Note that along the sides $Q_{y=0}$ and $Q_{y=1}$, and along the curve $\Pi^A - \Pi^{NA} = 0$, it results $\dot{y} = 0$. Conversely, along the sides $Q_{x=0}$ and $Q_{x=1}$, and along the curve $\Pi^P - \Pi^{NP} = 0$, it results $\dot{x} = 0$. No equilibrium point generally[3] exists along the sides $Q_{x=0}$ and $Q_{x=1}$. Thus, the highest number of equilibrium points that can be generically observed is seven.

4.2 Stability conditions

The Jacobian matrix of the dynamical system (5) is:

$$J = \begin{bmatrix} (1-2x)\left(\Pi^P - \Pi^{NP}\right) + \left(\gamma_2 - \gamma_1 + \dfrac{\beta_2 - \beta_1}{2} y\right) x(1-x) & \left(\dfrac{\beta_2}{2} + \dfrac{\beta_2 - \beta_1}{2} x\right) x(1-x) \\ 2\left[(a+c-2b)x + b - c\right] y(1-y) & (1-2y)\left(\Pi^A - \Pi^{NA}\right) \end{bmatrix}$$

The behavior of the system near an equilibrium point is related to the eigenvalues of the Jacobian matrix at that point. Namely, an equilibrium point is locally attractive if all the eigenvalues have real parts that are negative. If any eigenvalue has a real part that is positive, the point is unstable and can be either a saddle or a source. Then, the following proposition can be easily checked.

Proposition 1: *The equilibrium points* F_1, F_2 *and* F, *when existing, are saddle points or sources.*

The eigenvalues of $(0,0)$ *are* $-\alpha < 0$ *in direction of* $Q_{y=0}$, *and* $c-d$ *in direction of* $Q_{x=0}$.

The eigenvalues of $(0,1)$ *are* $\frac{\beta_2}{2}-\alpha$ *in direction of* $Q_{y=1}$, *and* $d-c$ *in direction of* $Q_{x=0}$.

The eigenvalues of $(1,0)$ *are* $\alpha+\gamma_1-\gamma_2$ *in direction of* $Q_{y=0}$, *and* $a-d$ *in direction of* $Q_{x=1}$.

The eigenvalues of $(1,1)$ *are* $\alpha-\frac{\beta_2-\beta_1}{2}+\gamma_1-\gamma_2$ *in direction of* $Q_{y=1}$, *and* $d-a$ *in direction of* $Q_{x=1}$.

The signs of the eigenvalues reveal that at most two equilibrium points can be simultaneously attractive. If $d<a$, strategy A dominates NA and prospective offenders will find it more convenient to assault. Thus, the only equilibrium points that can be attractive are $(0,1)$ and $(1,1)$ representing respectively the Surrender and All-Round Fight scenarios. The equilibrium points $(0,1)$ and $(1,1)$ will be simultaneously attractive if it also results (see Figure 1):

$$\frac{\beta_2}{2}<\alpha<\gamma_2-\gamma_1+\beta_2-\beta_1 \tag{6}$$

If $d>c$, strategy NA dominates A, prospective offenders will find it more convenient *not* to assault, and the only equilibrium points that can be attractive are $(0,0)$ and $(1,0)$ representing respectively the Peace and Deterrence scenarios. The equilibrium points $(0,0)$ and $(1,0)$ will be simultaneously attractive if it also results (see Figure 2):

$$\alpha < \gamma_2 - \gamma_1 \tag{7}$$

If $a < d < c$, the only equilibrium points that can be attractive are $(0,1)$ and $(1,0)$ representing respectively the Surrender and Deterrence scenarios. These points will be simultaneously attractive if it also results (see Figure 3):

$$\frac{\beta_2}{2} < \alpha < \gamma_2 - \gamma_1 \tag{8}$$

If $a < d < c$, another possibility is that all equilibrium points are simultaneously sources or saddles, which happens if it also results:

$$\gamma_2 - \gamma_1 < \alpha < \frac{\beta_2}{2} \tag{9}$$

In this case, all the trajectories that start in the interior of Q converge to the boundary of the square, indefinitely rotating clockwise (see Figure 4). This result resembles the typical behavior obtained by Cressman et al. (1998), for which the crime rate can be cyclical over time when property owners can exert private effort to prevent theft.

5 Interpretation of the results

In this section, we provide a systematic interpretation and a commentary of the results described in abstract mathematical terms in the previous section. For brevity, we do not discuss the cases occurring only if equality conditions on parameter values are satisfied, because any minimal perturbation in such values would lead to one of the dynamic regimes described in Figures 1–4.

The social dynamics of the model basically generate three different regimes, one of which further gives rise to two distinct sub-regimes. Their variety depends on the relative magnitude of the returns from the various options for prospective offenders. In particular, the dynamic regimes depend on the relative position of the ‘free’ parameter *d* (the payoff from not assaulting) with respect to the parameters c and a (the highest and lowest possible payoffs from assaulting). We recall that the best possible situation for the offender is when no potential victim self-protects (payoff c), whereas the worst possible situation is when all potential victims do so (payoff a). The first regime emerges when $d < a$ and is called the "No Way Out" regime. The second emerges when $d > c$ and is called the "Outside Option" regime. The third emerges when $a < d < c$, it is called the "Critical" regime and it gives rise to the sub-regimes called "Tug of War" and "Rock-Scissors-Paper".

With the exception of the Rock-Scissors-Paper sub-regime, whose dynamics are cyclical, all the other cases have attractive equilibrium points. These equilibrium points are attractive under any evolutionary dynamics that preserve the sign of the time derivatives and, therefore, these results are not necessarily limited to the use of the standard replicator dynamics. Conversely, the dynamic properties of the Rock-Scissors-Paper sub-regime may change if different sign-preserving dynamics are used.

5.1 The "No Way Out" regime

The first regime is determined by the condition $d < a$. By not assaulting, prospective offenders get less than the worst possible case when assaulting (that is, when all potential victims self-protect). Offenders will have therefore a strong incentive to assault. This condition may derive from the low profitability of alternative illegal activities, or from the paucity of legal forms of income that prevent criminal activity. We call this dynamic the "No Way Out" regime because, no matter what happens, offenders will be up for crime. At most two attractive equilibrium points can be possible, the Surrender scenario where no potential victim self-protects and the All-Round Fight scenario where all potential victims do so.

The Surrender scenario is the only possible equilibrium when privately self-protecting is costly enough, that is, when it costs more than the additional damage, in case of assault, of being the only neighbor who does not self-protect. Such condition is $\alpha > \beta_2 - \beta_1 + \gamma_2 - \gamma_1$, so the additional damage is both material and psychological. Conversely, the All-Round Fight scenario is the only possible equilibrium when privately self-protecting is cheap enough, that is, when it costs less than the expected material damage of being assaulted when nobody self-protects. Such condition is $\alpha < \beta_2/2$.

The Surrender and All-Round Fight equilibria are contemporarily possible if condition (6) holds, that is, when the cost of privately self-protecting ranges between $\beta_2/2$ and $\beta_2 - \beta_1 + \gamma_2 - \gamma_1$. The long-run equilibrium will depend on the initial distribution of behavioral types across the two populations or, in other words, to the cultural background of the community. We show this dynamic in Figure 1.

The Surrender scenario will prevail if both criminal and self-protective behaviors are initially low enough, or if these behaviors are highly disproportionate (that is, if the assault rate is low when self-protective choices are high, and vice versa). Under such conditions, private self-protection is relatively costly with respect to the risk of being assaulted, because the latter will be shared among sufficiently many exposed victims. The material damage of being assaulted would not be large enough to make self-protection cost-effective, therefore, the few individuals who self-protect will abandon this choice and they will join the great majority of vulnerable victims.

The All-Round Fight scenario will prevail if self-protective behaviors are high enough. Indeed, as crime increases, the few remaining vulnerable victims will be assaulted so often that they will find it more convenient to self-protect. This result is coherent with the idea that a higher risk of victimization encourages self-protection.

5.2 The "Outside Option" regime

The second regime is determined by the condition $d > c$. By not assaulting, prospective offenders get more than the best possible case when assaulting (that is, when nobody self-protects) and they will have therefore a strong incentive not to assault. This condition may derive from the high profitability of alternative illegal practices, or from legal forms of income that prevent criminal behavior. The latter could be, for instance, a full-time job that implies constant social monitoring, or an unemployment benefit with compulsory lifelong learning program. We call this dynamic the "Outside Option" regime because prospective offenders will eventually not assault anybody. At most two attractive equilibrium points can be possible, the Peace scenario where no potential victims self-protect and the Deterrence scenario where all potential victims do so. A good reason to self-protect, despite offenders are relatively unwilling to attack, is to avoid the emotional distress of being the most vulnerable neighbor (see also Section 2).

The Peace and Deterrence equilibria are contemporarily possible if condition (7) holds, that is, when the cost of private self-protection is lower than the emotional distress from not protecting when the others do so. Conversely, the Peace scenario is the only possible equilibrium when condition (7) does not hold and privately self-protecting is relatively too costly with respect to such psychological externality. Again, when both equilibrium points are possible, the eventual scenario will depend on the initial distribution of behavioral types across the two populations. We show this dynamic in Figure 2.

As assaulting is relatively inconvenient, the share of actual offenders will decline rather quickly. If most individuals do not self-protect, being assaulted becomes relatively unlikely, because such risk is spread over a large number of equally-exposed victims. Thus, eventually, no one will find it convenient to self-protect, and the Peace scenario will prevail. Conversely, if most individuals initially self-protect, the few vulnerable victims will run a high risk of assault even if actual offenders are relatively few. The emotional distress from being more vulnerable will eventually lead potential victims to self-protect, even if the share of offenders declines in time. This effect is coherent with evidence on persistent levels of fear after a decrease in crime, reported by Lewis and Maxfield (1980), Heath et al. (2001), and Hermann (2009).

5.3 The "Critical" regime

The third, most complex and interesting regime is determined by the condition $a < d < c$. Prospective offenders have no dominant strategy and should choose whether or not to assault by careful evaluating other contextual conditions. Sometimes offenders play tough, and sometimes not, depending on circumstances. The actual dynamic behavior in this regime basically depends on specific parameter conditions. Suitable parameter changes may bring about substantial modifications of the model dynamics (for instance, through a bifurcation). Thus, we name this situation the "Critical" regime, and we further distinguish two distinct sub-regimes called "Tug of War" and "Rock-Scissors-Paper".

5.3.1 The "Tug of War" sub-regime

The first sub-regime (determined by the condition $a < d < c$) exists if condition (9) does *not* hold. The possible equilibrium points can be the Surrender scenario (0,1) and the Deterrence scenario (1,0), and these scenarios are contemporarily possible if condition (8) holds. Accordingly, the cost of self-protection should be higher than the (expected) material damage of being assaulted when nobody self-protects, but still lower than the emotional distress from not protecting when the others do so. A tradeoff between material and psychological damage is then observable. Material conditions would make it relatively reasonable not to self-protect, because the loss from being assaulted is not large enough to make protection cost-effective, but this resigned behavior would give the green light to crime. On the other hand, the emotional distress from being the most vulnerable neighbor is substantial enough to make self-protection a viable choice, and this defensive behavior could progressively eradicate crime. The scenario that will eventually prevail will depend on the complex interplay of *all* of the parameters of the model, including initial conditions. We show this dynamic in Figure 3.

It should be clear now why we call this sub-regime “Tug of War”. As in the homonymous game, either victims or offenders conquer the field depending on which factors ‘pull’ more strongly toward the eradication or promotion of crime. To further confirm this intuition, we have that, if α drops below $\beta_2/2$ (and protection becomes relatively cheap in all respects), only the Deterrence scenario can be a possible equilibrium, whereas if α climbs above $\gamma_2-\gamma_1$ (and protection becomes so expensive that overcomes any kind of material or psychological damage), only the Surrender scenario can eventually result.

5.3.2 The “Rock-Scissors-Paper” sub-regime

The second sub-regime, determined by the condition $a<d<c$, exists if condition (9) holds. Accordingly, the cost of self-protection should be higher than the emotional distress from not protecting when the others do so, but still lower than the (expected) material damage of being assaulted when nobody self-protects. In this case, we have a perpetually oscillating behavior, as in the model by Cressman et al. (1998). It is interesting to discuss why we obtain a cyclic behavior rather than convergence to a stable state. After all, as in the Tug of War sub-regime, here too we have a non-trivial tradeoff between material and psychological costs. How come that the resulting social dynamics are so different? The answer lies in the relationship between relative material and psychological costs, and in the interaction between victims. In the Rock-

Scissors-Paper sub-regime, material damage is high and the psychological externality is low with respect to the cost of protection. When the share of victims who self-protect increases, assaulting becomes less rewarding for offenders and the frequency of assaults decreases. However, when crime decreases to a significant degree, potential victims progressively give up self-protecting, also because they are relatively less sensitive to the emotional distress of being more vulnerable. Such reaction generates a massive decrease of self-protected victims and, consequently, new opportunities for prospective offenders arise. The frequency of assaults begins to grow again, thus encouraging a defensive response from victims who restart to invest in self-protection, until the cycle is completed and a similar new one begins. We show this dynamic in Figure 4.

It should be clear now why we call this sub-regime "Rock-Scissors-Paper". Like in the famous game (and in its corresponding game-theoretic representation, see for example Friedman, 1991) there is a cyclic dynamic that prevents the achievement of a stable equilibrium. The Tug of War sub-regime, instead, tends to an equilibrium although the dynamic is initially similar (namely, an increase in self-protected victims that reduces the share of actual offenders). This fact depends on the psychological externality that self-protected individuals inflict to their more vulnerable neighbors. Potential victims are aware that most individuals are self-protecting, so they can feel the urge to self-protect too against offenders. In the Rock-Scissors-Paper sub-regime, such emotional pressure is relatively low, therefore defensive behaviors will decline as the crime rate decreases (and vice versa, following a cyclic dynamic). Conversely, in the Tug of War sub-regime, the emotional distress is relatively high and can support defensive behaviors, even with declining crime rates, so that the dynamics can eventually converge to the Deterrence scenario (1,0).

5.4 The role of psychological externalities

The negative externality that self-protected individuals inflict to their neighbors in form of emotional distress, plays a key role in our study and deserves further discussion. The introduction of such psychological externality allows to increase the range of possible dynamics that we obtain from the seminal paper by Cressman et al. (1998). In the latter, crime rate and private effort against crime typically follow cyclical paths similar to our Rock-Scissors-Paper sub-regime. The inclusion in our model of psychological externality, among other factors, permits to obtain bi-stable dynamics in addition to such cyclic behavior, and the existence of various dynamic regimes leads to significant improvements in welfare and policy analysis. Thus, the psychological externality does not simply add realism to the model but it also extends its predictive power of the social dynamics of crime.

We recall from Section 2 that the psychological externality can have three reasons, all supported by relevant lines of research. First, the perception of being relatively more exposed than the others to criminal assaults, when the others increase their level of protection, can amplify the fear of crime (see Heath et al., 2001). Second, the distress can arise from observing the defensive behaviors of others, which reminds the risks and the potential costs of being a victim. This aspect can increase the fear or worry about crime in individuals previously adapted to local crime rate (see Taylor and Shumaker, 1990). Third, individuals can also care about their *relative* position in society and being the least protected neighbor may affect their subjective well-being, even if there is absolutely no risk of victimization (see Luttmer, 2005).

6 Welfare and policy analysis

6.1 Welfare analysis

In this section, we compare the equilibrium points of the game in terms of welfare and efficiency, from the perspective of victims. A state of the system is more efficient than another state (in the economic sense of Pareto) if, when moving from the former to the latter, the welfare of at least one individual decreases. As usual, we measure welfare by means of the average payoff. This measure corresponds for victims to the individual payoff in equation (3) when $x = 0$ (as in the Peace and Surrender scenarios), and to the individual payoff in equation (4) when $x = 1$ (as in the Deterrence and All-Round Fight scenarios). Then, the following proposition holds.

Proposition 2: *In the No Way Out regime (i.e. when $d < a$), the Surrender scenario* (0,1) *is more efficient for victims than the All-Round Fight scenario* (1,1) *if and only if* $\gamma_1 > \frac{\beta_2}{2} - \alpha$.

In the Outside Option regime (i.e. when $d > c$), the Peace scenario (0,0) *is always more efficient for victims than the Deterrence scenario* (1,0).

In the Critical regime (i.e. when $a < d < c$), the Surrender scenario (0,1) *is more efficient for victims than the Deterrence scenario* (1,0) *if and only if* $\gamma_1 > \frac{\beta_2 - \beta_1}{2} - \alpha$.

The proposition is immediately verified by comparing the payoffs of victims in the various states, computed from equations (3) and (4). An immediate corollary, by conditions (6)–(8), is the following. When two attractive equilibrium points contemporarily exist, then the equilibrium with $x = 0$ (when nobody self-protects) is always more efficient for victims than the equilibrium with $x = 1$ (when everybody self-protect). This assertion may still hold even when only the latter equilibrium is attractive.

The interpretation of Propositions 2 is simple if we keep in mind the meaning of its conditions. In the No Way Out regime, the attractive equilibria can be the Surrender and All-Round Fight scenarios. The Pareto efficiency between the two depends on three elements: the cost of self-protecting, α; the expected damage for criminal assault if nobody self-protects, $\beta_2/2$; and the negative externality for self-protected individuals whose neighbor self-protects, γ_1. In particular, the defensive behavior is socially inefficient for victims if it costs more than the difference between the expected material damage when nobody self-protects ($\beta_2/2$) and the emotional distress when everybody self-protect (γ_1). We can think of the latter quantity as an *endogenous intrinsic* fear, that is, the fear that victims generate by doing everything they could to protect themselves. When protection is costly and there is such intrinsic fear, and if their overall cost overcomes the expected damage without protection, victims cannot collectively improve their welfare by self-protecting. Giving up (as in the Surrender scenario) would be therefore more efficient than resisting against crime (as in the All-Round Fight scenario).

In the Critical regime, the attractive equilibria can be the Surrender and Deterrence scenarios. The condition for Pareto efficiency is similar to that in the No Way Out regime, with the difference that now it is *less* restrictive. Indeed, the cost of protection and of the intrinsic fear should now overcome the expected *incremental* damage for criminal assault when nobody self-protects (with respect to when everybody do so). If so, victims would be better off without self-protecting (as in the Surrender scenario) despite this behavior gives the green light to crime.

In the Outside Option regime, the attractive equilibria can be the Peace and Deterrence scenarios. Prospective offenders will eventually not assault anybody, so material considerations would make it relatively convenient for victims not to self-protect. However, victims could still defend themselves (and the Deterrence equilibrium may consequently emerge) because of psychological considerations. A great fear of being victimized, for example, can push the social dynamics toward self-protection in spite of the steady decline (and of the eventual disappearance) of criminal activity. Since protection is costly and creates a negative externality, Peace will always be more efficient than Deterrence.

6.2 Public security and social welfare

We study the effects of public policy on social welfare, and we assume that the Government taxes potential victims and uses the revenues to provide public security (or appropriate social care) against crime. With public intervention, the payoff matrices (1) and (2) of potential victims and prospective offenders become, respectively:

$$\begin{array}{ccccc} & A,P_{N2} & A,NP_{N2} & NA,P_{N2} & NA,NP_{N2} \\ P_{N1} & -\alpha-\frac{1}{2}\beta_1-\gamma_1-\tau_1 & -\alpha-\tau_1 & -\alpha-\gamma_1-\tau_1 & -\alpha-\tau_1 \\ NP_{N1} & -\beta_2-\gamma_2-\tau_2 & -\frac{1}{2}\beta_2-\tau_2 & -\gamma_2-\tau_2 & 0-\tau_2 \end{array}$$

$$\begin{array}{ccccc} & P_{N1},P_{N2} & P_{N1},NP_{N2} & NP_{N1},P_{N2} & NP_{N1},NP_{N2} \\ A & a-p & b-p & b-p & c-p \\ NA & d & d & d & d \end{array}$$

where τ_1 and τ_2 is the taxation for, respectively, protected and unprotected victims, with $\tau_1 \geq \tau_2 > 0$, and $p > 0$ represents the deterrent effect of public expenditures on criminal behavior, which reduces the expected payoff of the actual offenders. The effects of p on the system dynamics are the same if, instead of subtracting it from the payoffs of strategy *A*, we add it to the payoffs of strategy *NA*. In this form, the parameter p can represent the effects of improved social care against crime, which increases the income of legal activities for the inactive (or not recidivist) offenders. The provision of social care can take the form of unemployment benefits and active labor market programs, which prevent from being involved in crime.

As p grows, the system dynamics will shift progressively to the Outside Option regime. Therefore, for a high enough p, the offenders' dominant strategy would be *not* to assault and all prospective offenders would become inactive. Empirical support for this finding is provided by Krieger and Meierrieks (2010). The possible attractive equilibria would eventually become the

Peace and Deterrence scenarios. We know from Proposition 2 that the Deterrence scenario is Pareto inefficient. so public policy should prevent the corresponding equilibrium point $(x, y) = (1,0)$ from becoming attractive. In other words, after having eradicated crime, the Government should prevent victims from buying superfluous self-protection when there is no risk of being assaulted. Such inefficient behavior is possible because of the psychological externality that self-protected individuals inflict to their more vulnerable neighbors, as exposed in Section 5.2. Additionally, victims could erroneously think that offenders do not assault them thanks to their private efforts and not because of the Government intervention.

The Government can improve welfare by financing the appropriate policies through taxation. If $\tau_1 = \tau_2$, taxation does not discriminate between victims and does not change the payoff differential between the victims' strategies. Thus, such equal taxation has no impact on the dynamic properties of the system and is not capable of preventing inefficient outcomes. Conversely, by increasing τ_1 while keeping τ_2 constant, the Government can prevent the inefficient Deterrence scenario and influence the social dynamics toward the more efficient Peace scenario $(x, y) = (0,0)$. Through discriminatory taxation of self-protective behaviors, the Government may therefore finance the appropriate public policy against crime and improve the social welfare of victims. The scope for public intervention appears substantially extended than in the seminal model by Cressman et al. (1998), in which crime rate typically follows cyclical paths and public intervention can detrimentally increase the average crime rate by 'crowding out' private self-protection. In our model, public intervention can undertake effective measures to improve welfare by contrasting the effects of psychological externalities, like the fear of crime.

7 Conclusions

In this paper, we have proposed a model for the social dynamics of crime, based on evolutionary game theory. Potential victims can privately self-protect against prospective offenders, but such defensive behavior imposes two types of negative externalities on neighbors. There is a *material* externality, well known in the economics literature, in that self-protection creates an incentive for the criminal to victimize the neighbor. The second type of externality has been the focus and novelty of the paper. An individual who self-protects can impose a *psychological* externality on the neighbors, because this behavior can increase their fear of crime and their concerns for relative social position. We have reviewed three lines of empirical research that supports this assumption, namely, on perceived risk of victimization (e.g. Heath et al., 2001), on loss of adaptation to crime (e.g. Taylor and Shumaker, 1990), and on the marketization of security as a positional good (e.g. Loader, 1999; Luttmer, 2005). We have found that psychological externalities can encourage victims to self-protect even with constant or declining crime rates, and this circumstance may lead to socially inefficient outcomes because of the excessive expense in private protection. Then, providing higher levels of public security (or of appropriate social care), financed through discriminatory taxation of private defensive behaviors, can deter crime and reduce superfluous self-protective expenses, therefore improving efficiency. This result represents a further development of earlier findings by Cressman et al. (1998). Our conclusion explains also the empirical results by Krieger and Meierrieks (2010), who have found a significant correlation between appropriate social policies and a reduction of crime.

A major conclusion of our analysis is that the dynamics of crime depend on subtle interactions among economic, social and psychological elements. This concept has been earlier pointed out by Braithwaite (2000) and is related to the contemporary transition to a ‘risk society’ (Beck, 1992) where social and psychological elements play an increasing role in the context of safety. Still, the literature seems to lack an interdisciplinary framework that brings together the concepts of the economics of crime with the insights from sociology and psychology. Filling this gap requires a formidable amount of work, in that it is necessary to acquire a profound knowledge of very different streams of literature and of alternative methodological approaches, which should be combined creatively and fruitfully into a suitable analytical framework. This paper is a first attempt to fill this gap and we hope that it will stimulate the achievement of this goal.

References

Amendola G. (1997), *La città postmoderna: magie e paure della metropoli contemporanea*, Latenza, Bari.

Amendola G. (2003), *Paure in città*, Liguori, Naples.

Antoci A., Sacco P.L. (1995), "A Public Contracting Evolutionary Game with Corruption", *Journal of Economics* 61, 89-122.

Antoci A., Sacco P.L. (2002), "The Emergence of Deontological Codes in Public Administration", *Journal of Mathematical Sociology* 26, 271-308.

Bartel A.P. (1975), "An Analysis of Firm Demand for Protection Against Crime", *Journal of Legal Studies* 4, 443-478.

Beck, U. (1992), *Risk society: Towards a new modernity*. Sage, London.

Becker G.S. (1968), "Crime and Punishment: An Economic Approach", *Journal of Political Economy* 76, 169-217.

Bier V.M., Oliveros S., Samuelson L. (2007), "Choosing What to Protect", *Risk Analysis* 27, 607-620.

Björnerstedt J., Weibull J.W. (1995), "Nash Equilibrium and Evolution by Imitation", in K.J. Arrow, E. Colombatto, M. Perlman and K. Schmidt (eds.), The Rational Foundations of Economic Behaviour, IEA/Macmillan, London, 155-171.

Braithwaite J. (2000), "The New Regulatory State and the Transformation of Criminology", *British Journal of Criminology* 40, 222-238.

Chadee, D., Ng Ying, N. K. (2013), "Predictors of fear of crime: general fear versus perceived risk", *Journal of Applied Social Psychology* 43(9), 1896-1904.

Clotfelter C.T. (1977), "Public Services, Private Substitutes, and the Demand for Protection Against Crime", *American Economic Review* 67, 867-877.

Cook, P.J. (1977), “Punishment and crime: a critique of current findings concerning the preventive effects of punishment”, *Law and Contemporary Problems* 41, 164-204.

Covington, J., Taylor, R.B. (1991), “Fear of crime in urban residential neighborhoods”, *The Sociological Quarterly* 32, 231-249.

Cressman R., Morrison W.G., Wen J.-F. (1998), "On the Evolutionary Dynamics of Crime", *Canadian Journal of Economics* 31, 1101-1117.

Ehrlich, I., Becker, G.S. (1972), "Market Insurance, Self-Insurance, and Self-Protection", *Journal of Political Economy* 80, 623-648.

Farrall S., Bannister J., Ditton J. (2000), "Social Psychology and the Fear of Crime", *British Journal of Criminology* 40, 399-413.

Frey, B.S., Stutzer, A. (2002), “What Can Economists Learn from Happiness Research?”, *Journal of Economic Literature* XL, 402–435.

Friedman D. (1991), “Evolutionary Games in Economics”, Econometrica 59, 637-666.

Gabriel G., Greve W. (2003), "Psychology of Fear of Crime: Conceptual and Methodological Perspectives", *British Journal of Criminology* 43, 600-614.

Hale, C. (1996), “Fear of crime: A review of the literature”, *International review of Victimology* 4, 79-150.

Heal G., Kunreuther H. (2007), "Modelling Interdependent Risk", *Risk Analysis* 27, 621-634.

Heath, L., Kavanagh, J., Thompson, S. (2001), “Perceived vulnerability and fear of crime: Why fear stays when crime rates drop”, *Journal of Offender Rehabilitation* 33, 1–14.

Hermann P. (2009), "City Crime May Be Down, But Fear Endures", *The Baltimore Sun*, May 29.

Hofbauer J., Sigmund K. (1988), *The Theory of Evolution and Dynamical Systems*, Cambridge University Press, London.

Jackson J. (2008), "A Psychological Perspective on Vulnerability in the Fear of Crime", *Psychology, Crime, and Law* 15, 365-390.

Jones T., Newburn T. (2002), "The Transformation of Policing? Understanding Current Trends in Policing Systems", *British Journal of Criminology* 42, 129-146.

Kidder, L., Cohn, E. (1979), "Public views of crime and crime prevention", in Frieze, I.H., Bar-Tal, D., Carroll, J. (eds.), *New approaches to social problems*, Jossey-Bass Inc., San Francisco.

Krieger, T., Meierrieks, D. (2010), “Terrorism in the worlds of welfare capitalism”, *Journal of Conflict Resolution* 54, 902-939.

Lakdawalla D., Zanjani G. (2006), "Insurance, Self-Protection, and the Economics of Terrorism", *Journal of Public Economics* 89, 1891-1905.

Lewis, D.A., Maxfield, M.G. (1980), "Fear in the neighborhoods: An investigation of the impact of crime", *Journal of Research in Crime and Delinquency* 17, 160-189.

Liska, A.E., Sanchirico, A., Reed, M.D. (1988), “Fear of crime and constrained behavior specifying and estimating a reciprocal effects model”, *Social Forces* 66, 827-837.

Loader I. (1999), "Consumer Culture and the Commodification of Policing and Security", *Sociology* 33, 373-392.

Luttmer, E.F. (2004), *Neighbors as negatives: Relative earnings and well-being*, No. w10667, National Bureau of Economic Research.

Muermann A., Kunreuther H. (2008), "Self-Protection and Insurance with Interdependencies", *Journal of Risk and Uncertainty* 36, 103-123.

Newburn T. (2001), "The Commodification of Policing: Security Networks in the Late Modern City", *Urban Studies* 38, 829-848.

Norris, F.H., Johnson, K.W. (1988), “The effects of ‘self-help’ precautionary measures on criminal victimization and fear: lmplications for Crime-Prevention Policy”, *Journal of Urban*

Affairs 10, 161-181.

Norton, L., Courlander, M. (1982), “Fear of crime among the elderly: The role of crime prevention programs”, *The Gerontologist* 22, 388-393.

Reid, L. W., Konrad, M. (2004), “The gender gap in fear: Assessing the interactive effects of gender and perceived risk on fear of crime”, *Sociological Spectrum* 24, 399-425.

Rosenbaum D.P. (1988), "Community Crime Prevention: A Review and Synthesis of the Literature", *Justice Quarterly* 5, 323-395.

Rountree, P.W., Land, K.C. (1996), “Perceived risk versus fear of crime: Empirical evidence of conceptually distinct reactions in survey data”, *Social forces* 74, 1353-1376.

Sacco P.L. (1995), “Comment to Björnerstedt and Weibull”, in K.J. Arrow, E. Colombatto, M. Perlman and K. Schmidt (eds.), *The Rational Foundations of Economic Behaviour*, IEA/Macmillan, London, 172-181.

Schlag K. (1998), “Why Imitate, and If So, How? A Boundedly Rational Approach to Multi-armed Bandits”, *Journal of Economic Theory* 78, 130-156.

Silverman E., Della-Giustina J. (2001), "Urban Policing and the Fear of Crime", *Urban Studies* 38, 941-957.

Taylor, R.B., Shumaker, S.A. (1990), “Local crime as a natural hazard: Implications for understanding the relationship between disorder and fear of crime”, *American Journal of Community Psychology* 18, 619-641.

Van Dijk J.J.M. (1994), "Understanding Crime Rates. On the Interactions Between the Rational Choices of Victims and Offenders", *British Journal of Criminology* 34, 105-121.

Warr M., Ellison C.G. (2000), "Rethinking Social Reactions to Crime: Personal and Altruistic Fear in Family Households", *American Journal of Sociology* 106, 551-578.

Weibull J. (1995), *Evolutionary Game Theory*, Mit Press, Cambridge Mass.

Zedner L. (2006), "Policing Before and After the Police", *British Journal of Criminology* 46, 78-96.

Zhuang J., Bier V.M. (2007), "Balancing Terrorism and Natural Disasters - Defensive Strategy with Endogenous Attacker Effort", *Operations Research* 55, 976-991.

Figure 1. The “No Way Out” regime, leading to Surrender or All-Round Fight scenarios.

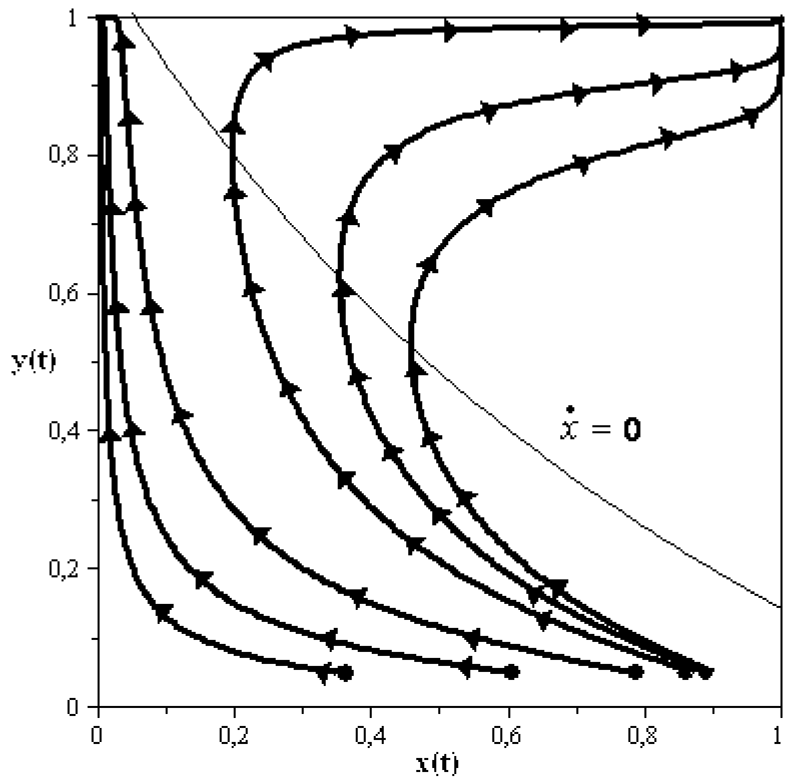


Figure 2. The “Outside Option” regime, leading to Peace or Deterrence scenarios.

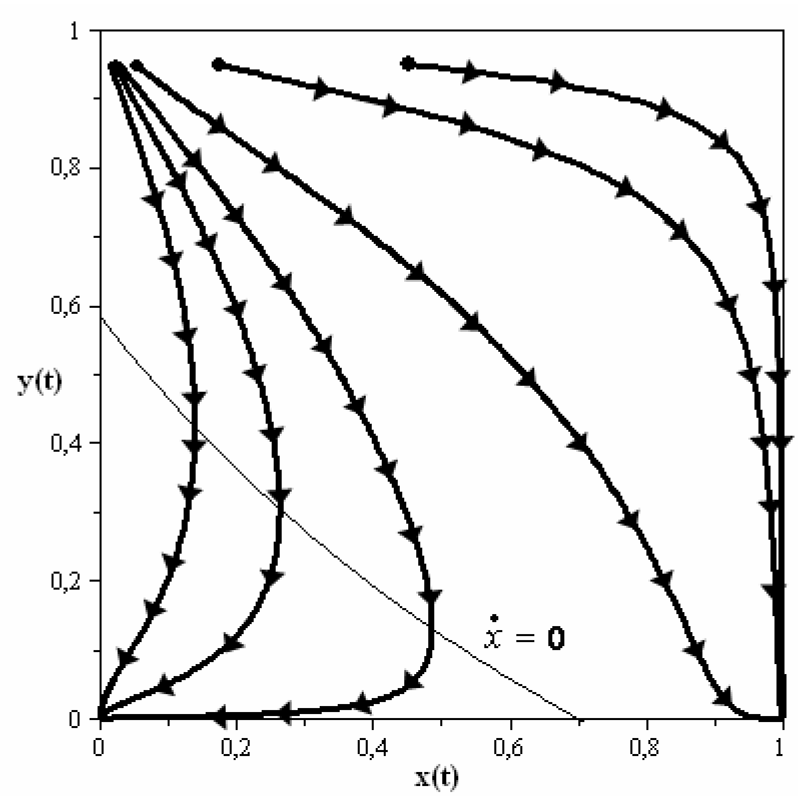


Figure 3. The “Tug of War” sub-regime, leading to Surrender or Deterrence scenarios.

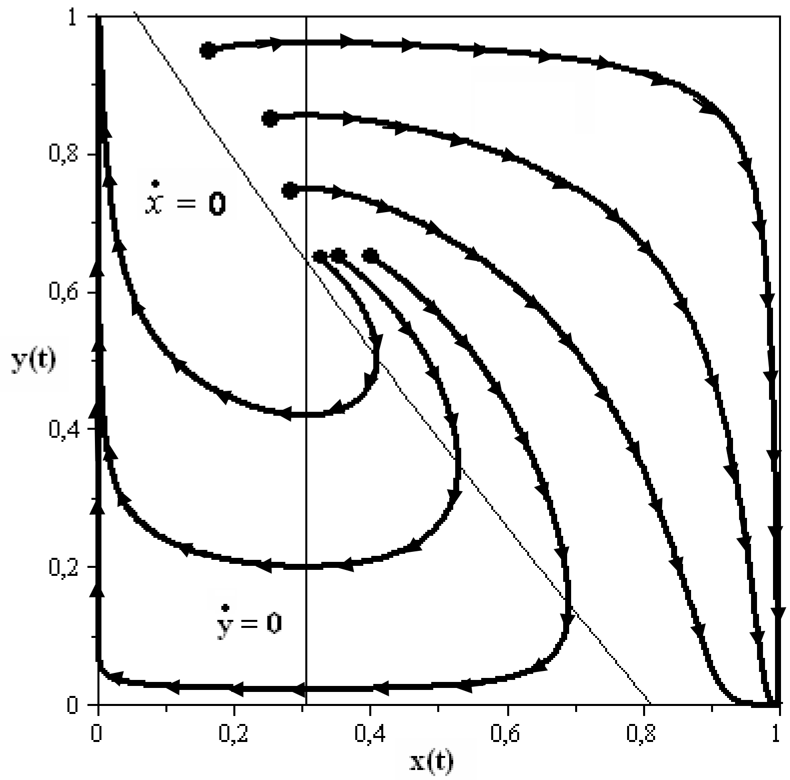
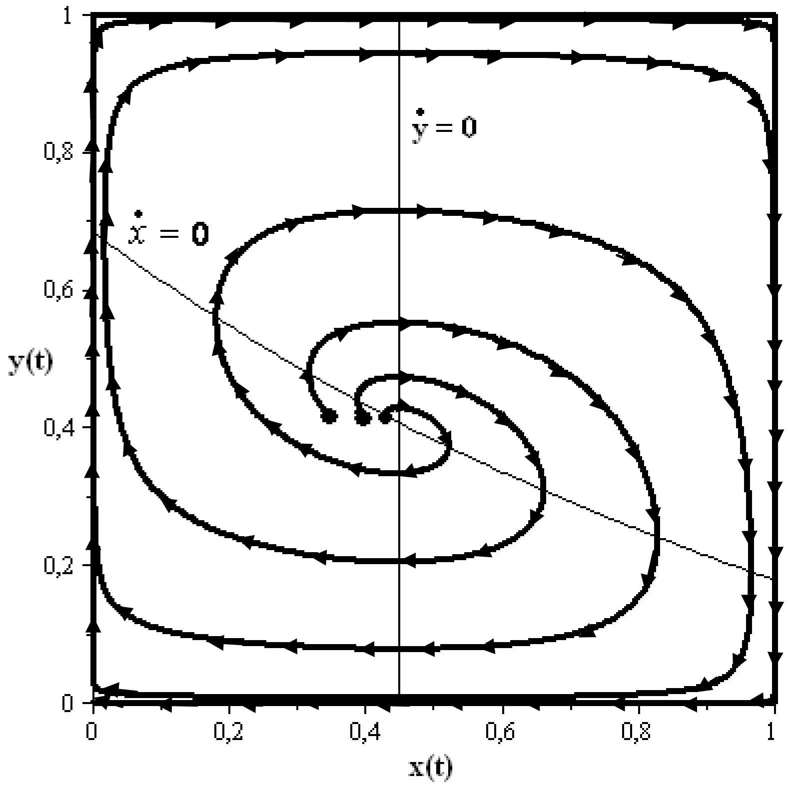


Figure 4. The "Rock-Scissors-Paper" sub-regime, with cyclic trajectories tending to the square boundary.



Endnotes

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[1] Conversely, the fear that individuals may instill in themselves through their own precautionary behavior against crime (as in Taylor and Shumaker, 1990) can be included in the parameter α .

[2] Consequently, the shares $1-x(t)$ and $1-y(t)$ represent the shares of potential victims playing strategy *NP* and of prospective offenders playing strategy *NA*, respectively.

[3] The side $Q_{x=0}$ is pointwise fixed for $d = a$ and the side $Q_{x=1}$ is pointwise fixed for $d = c$, but these properties are not robust to even minimal perturbations in the value of d . Indeed, any small change would lead to $d \neq a, c$ and therefore to the lack of equilibrium points along $Q_{x=0}$ and $Q_{x=1}$ in the general case (see also Zeeman, 1980).